US Army Natick Soldier Research, Development & Engineering Center

The Science Behind the Warrior: Yesterday, Today and Tomorrow

Bi/Tricomponent Fiber Extrusion - A New Method to Produce High Performance Fibers

Cleaner Technology and Energy Efficiency: Structuring a Competitive Advantage

April 5, 2007

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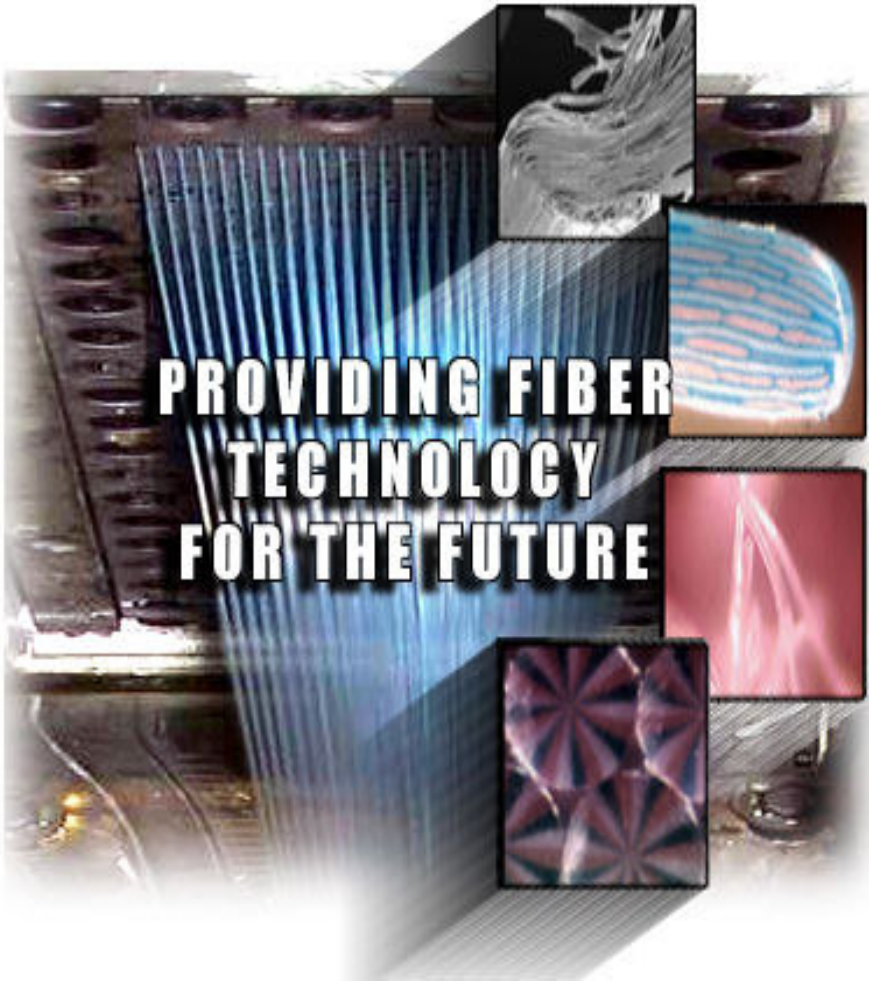
High Performance Fiber COE at the Natick Soldier RDEC, Natick MA

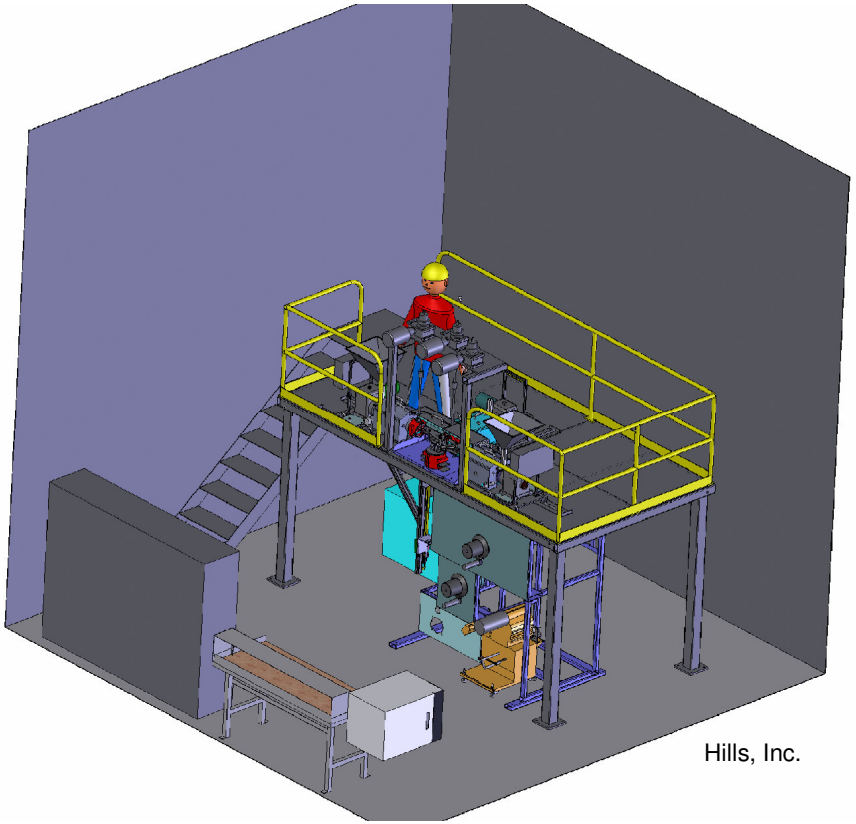
The goal of NSRDEC's High Performance Fiber COE is to collaborate with academic and industrial partners to invent and transition fiber technology for use in woven and non-woven textiles for high performance, dual-use applications such as environmental/ballistic/CB protection and electrotextiles. NSRDEC has extensive fiber extrusion capabilities as well as state-of-the-art analytical capabilities such as Instron mechanical analysis, thermal analysis, transmission and scanning electron microscopy, nuclear magnetic resonance spectroscopy, liquid chromatography/mass spectrometry, and x-ray diffractometry.



Bi/Tri-Component Fiber Extruder Capabilities

Research-scale Bi/tri-component Fiber Extruder:

- Capacity – 1 to 6 pounds/hour
- ¾ Inch Diameter Single Screw
- Temperature Limit – 350°C
- Three Melt Pumps are Thermally Isolated
- Nitrogen Ports for Oxygen Sensitive Polymers
- Draw Speed – 500-2500 meters/min.



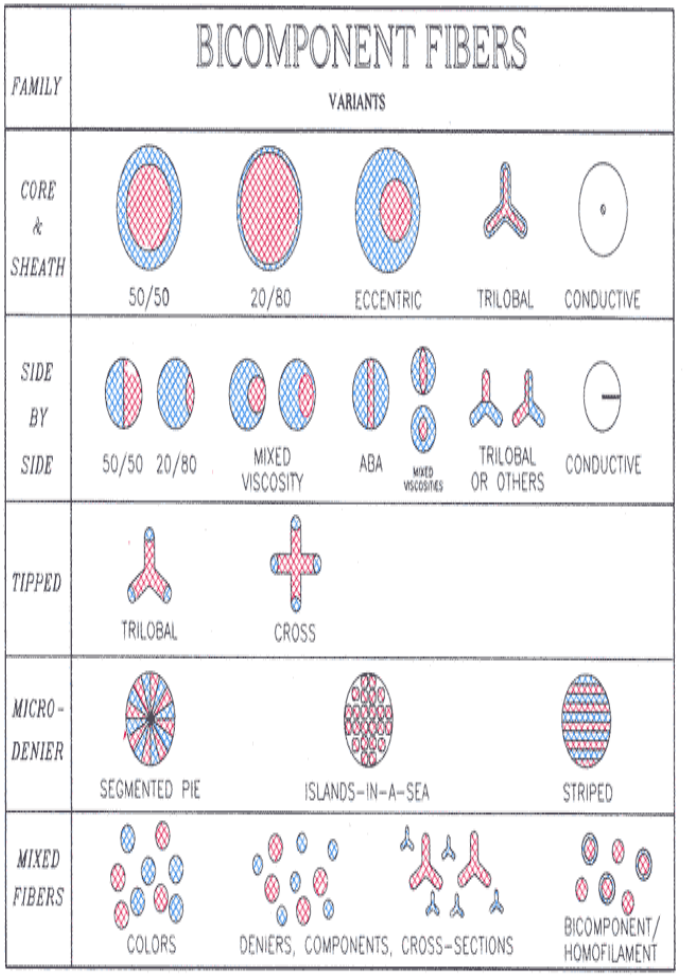
Hills, Inc.

Bi-component Fiber Cross Sections

Bi-component spinning technology, which includes side-by-side, sheath/core, islands in the sea and segmented pie morphologies will lead to the development of lighter, reactive/responsive fabrics that will make the wearer safer, more comfortable and higher performing.

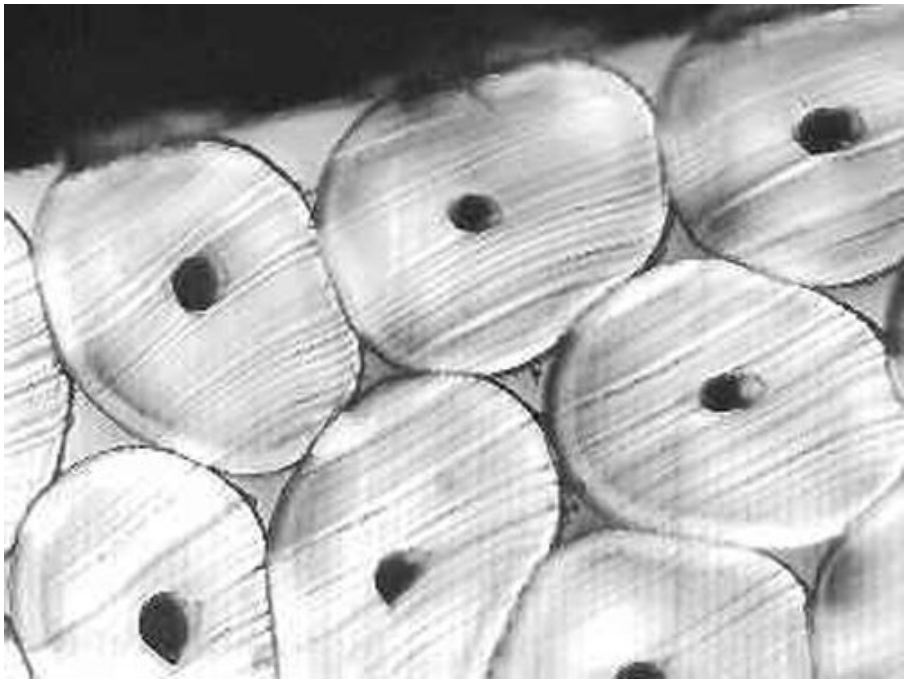
Bi-component fibers can also be used in applications besides clothing, to include soft shelters, parachutes, vehicles and numerous household fabrics.

The COE will utilize the expertise of NSRDEC engineers, chemists and textile technologists, along with fiber manufacturing experts in academia and industry to create and transition these new high performance fibers.

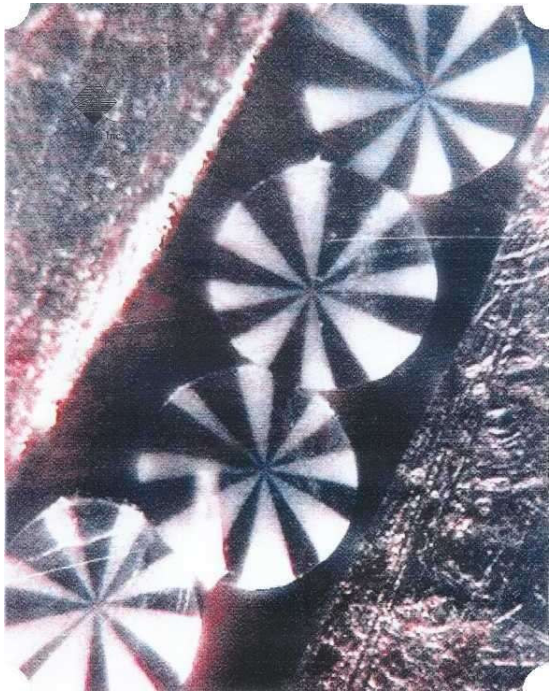


Metal Core and Segmented Pie Cross-Sections

Increased heat or electrical transfer conductivity is possible



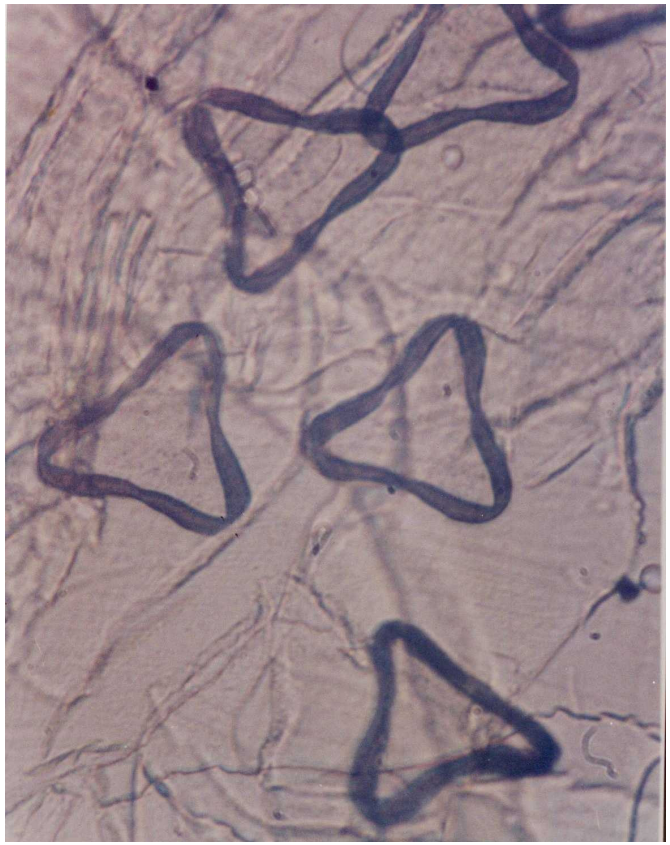
Metal Core Fibers could be used in electrotextile applications

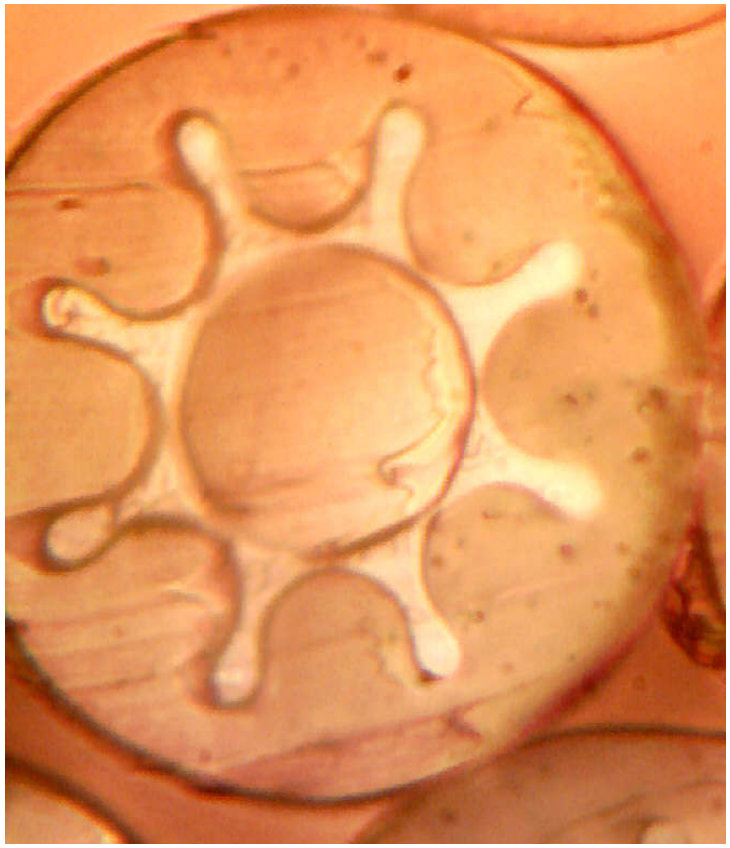


Segmented pie and side-by-side configurations can be split to obtain greater surface area for reactive additives

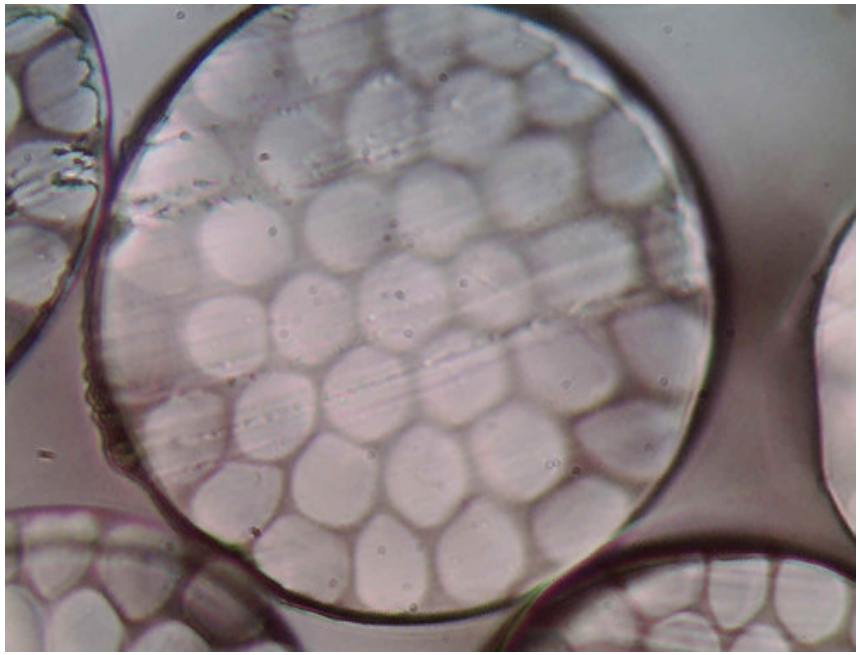
Complex, Sheath-Core Cross-Sections

Increased material surface area is possible through tailoring fiber cross-section geometry

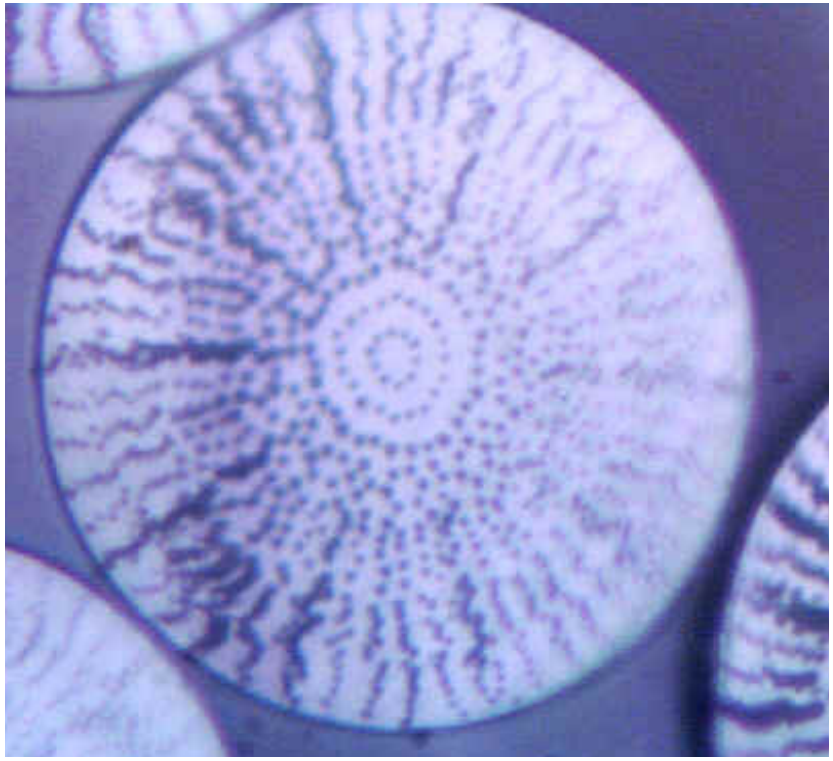




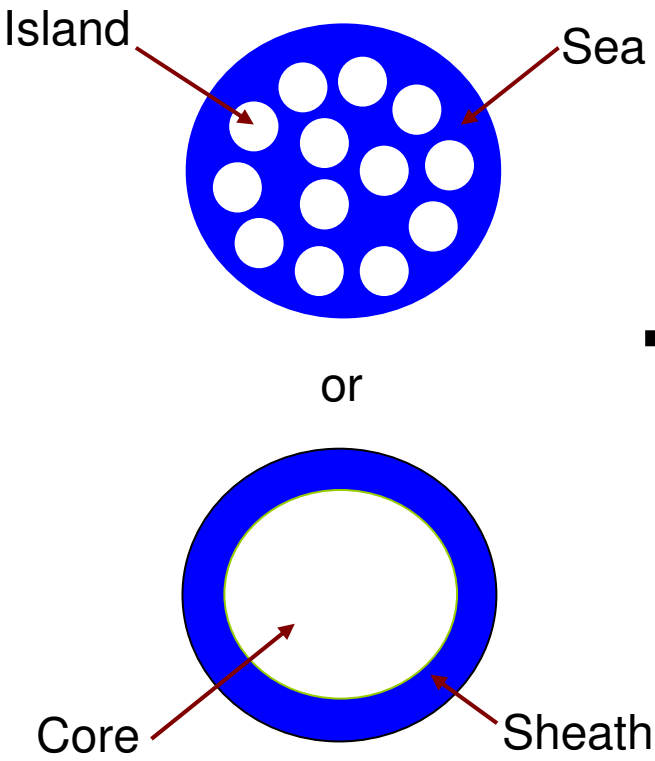
Islands-in-the-Sea (INS) Fibers



Islands-in-the-Sea can be used to make thermoplastic nanofibers

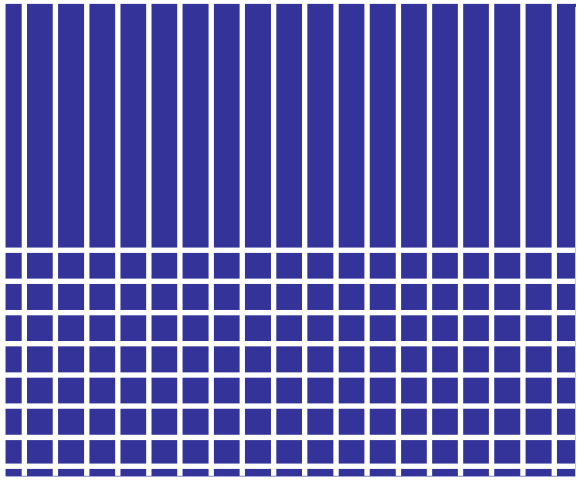


Transparent Fiber Composite Fabrication



Heat

Pressure

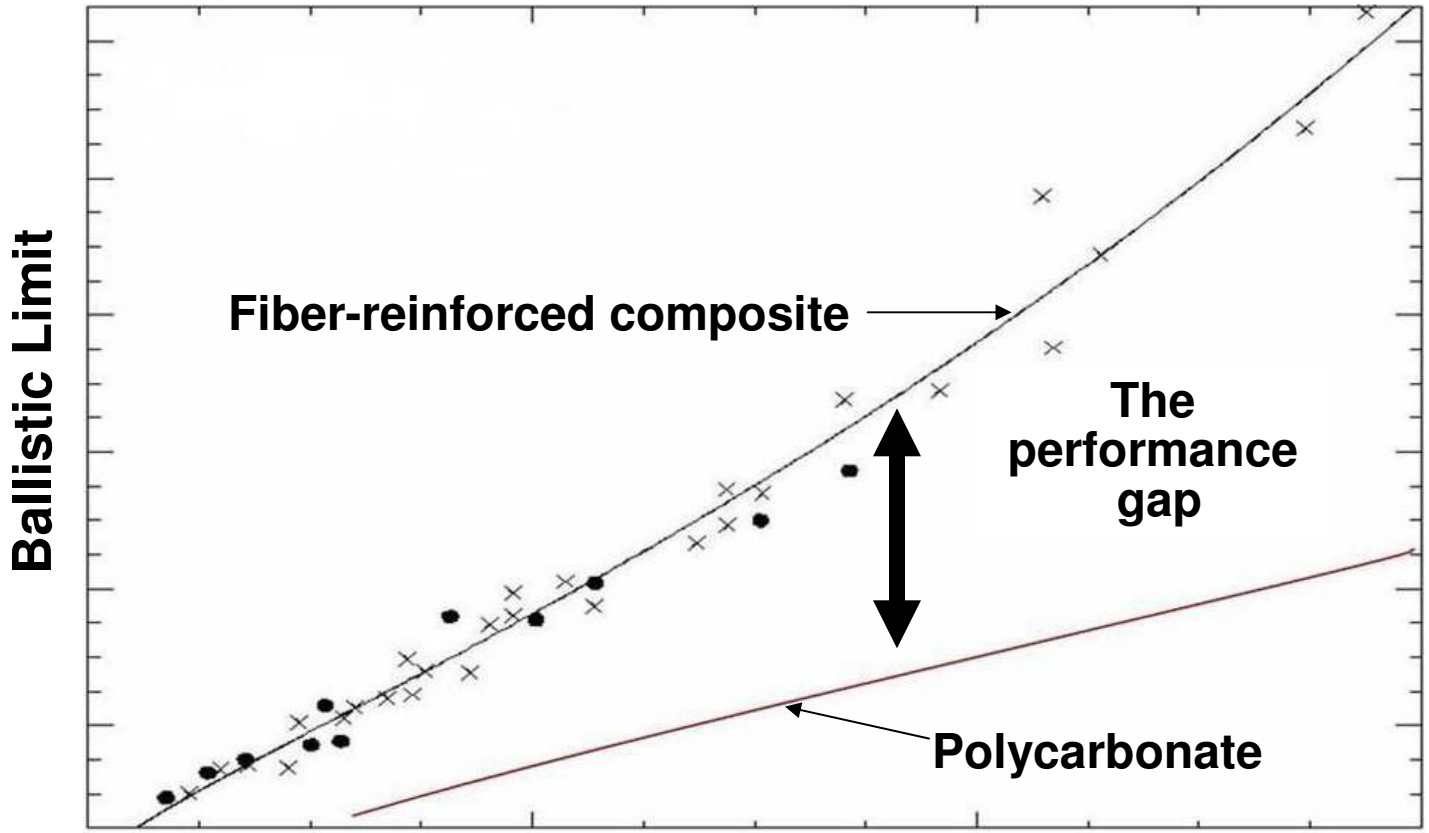


Consolidated Transparent Composite

Light scattering may be prevented by refractive index matching or using nano-scale reinforcing fibers

Enhanced Transparencies for Ballistic Protection

Ballistic Limit
Monolithic polymers vs. Fiber-reinforced polymer composites

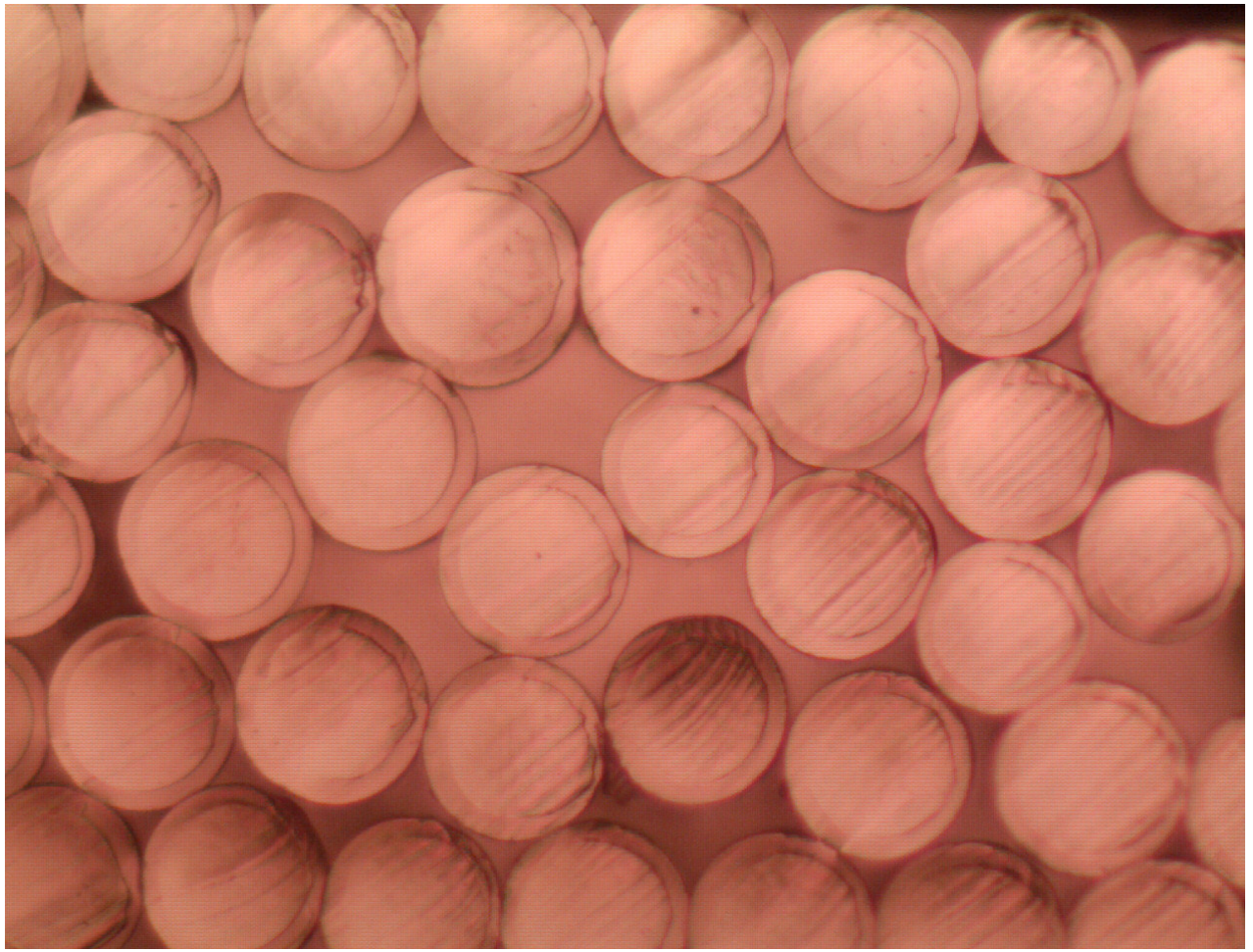


Physical/Mechanical Properties of Candidate Polymers

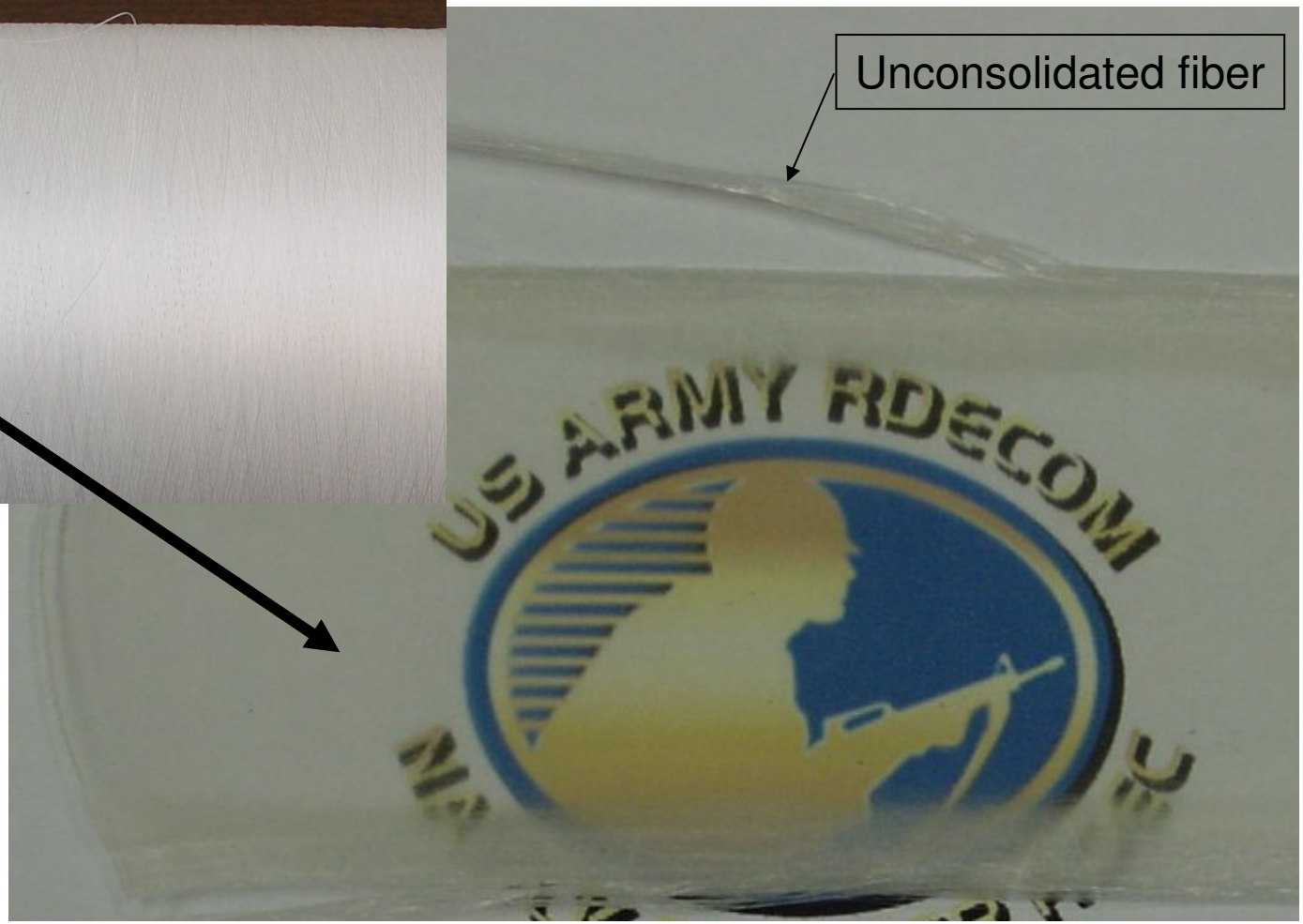
Polymer	Morphology	Density	Refractive Index	Tensile Strength (MPa)	
		(g/cc)	(nD20)	Fiber Form	Injection Molded
Polycarbonate	Amorphous	1.20	1.587	230	55-75
PMMA (Acrylic)	Amorphous	1.19	1.490	69	63
Semi-aromatic polyamide T5000	Amorphous	1.12	1.566	79	90
Cyclo-aliphatic polyamide CX7323	Semi-crystalline	1.02	1.516	189	60
Polypropylene	Semi-crystalline	0.90	1.490	400-800	25-40
Cyclo-aliphatic polyolefin 1020R	Amorphous	1.01	1.53	150	53
Cyclo-aliphatic polyolefin E48R	Amorphous	1.01	1.53	36	71

"Sheath/Core" (S/C) Fiber Cross-Section

Polypropylene Sheath/Core (undrawn fiber)



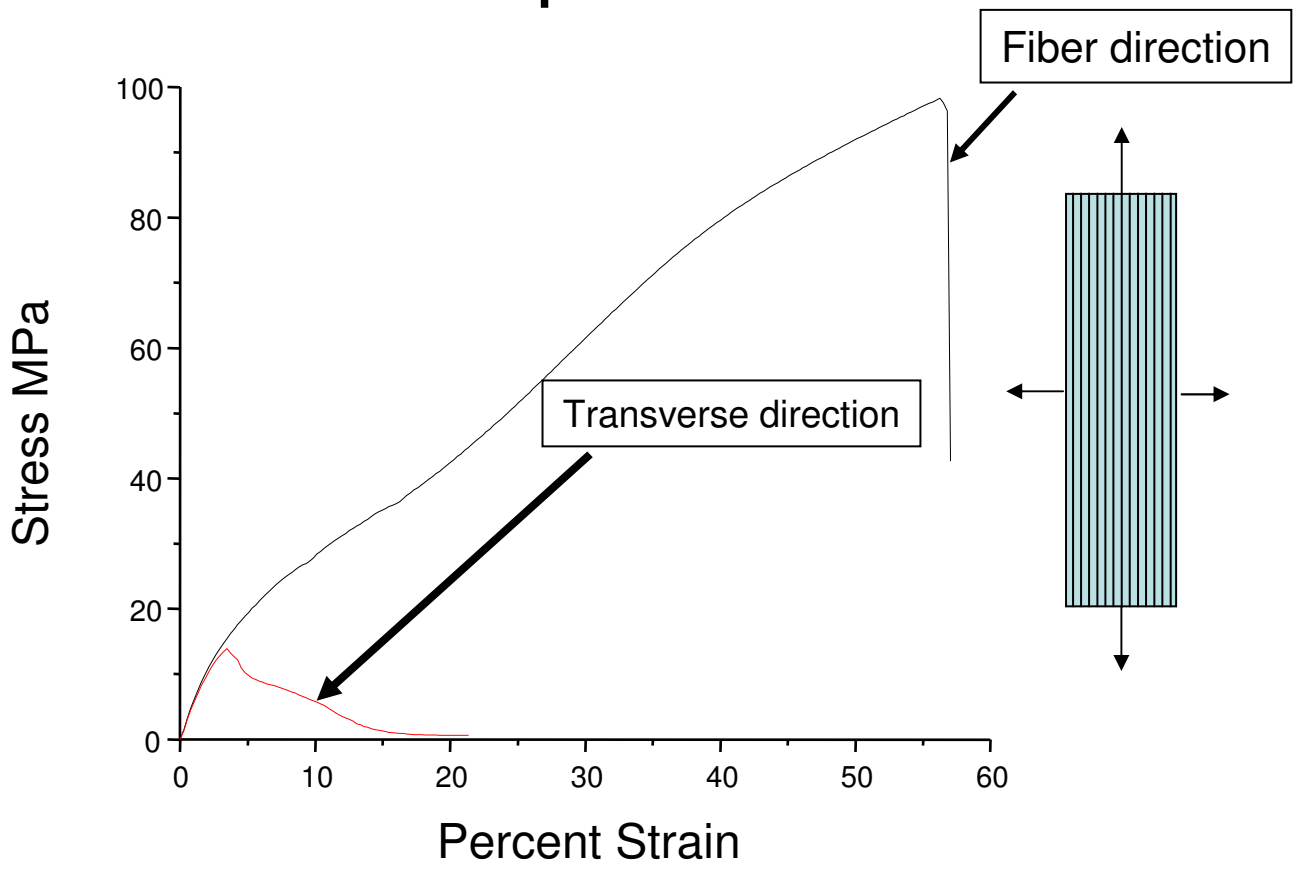
Composites from Fibers



Bi-component fiber transformed to consolidated part

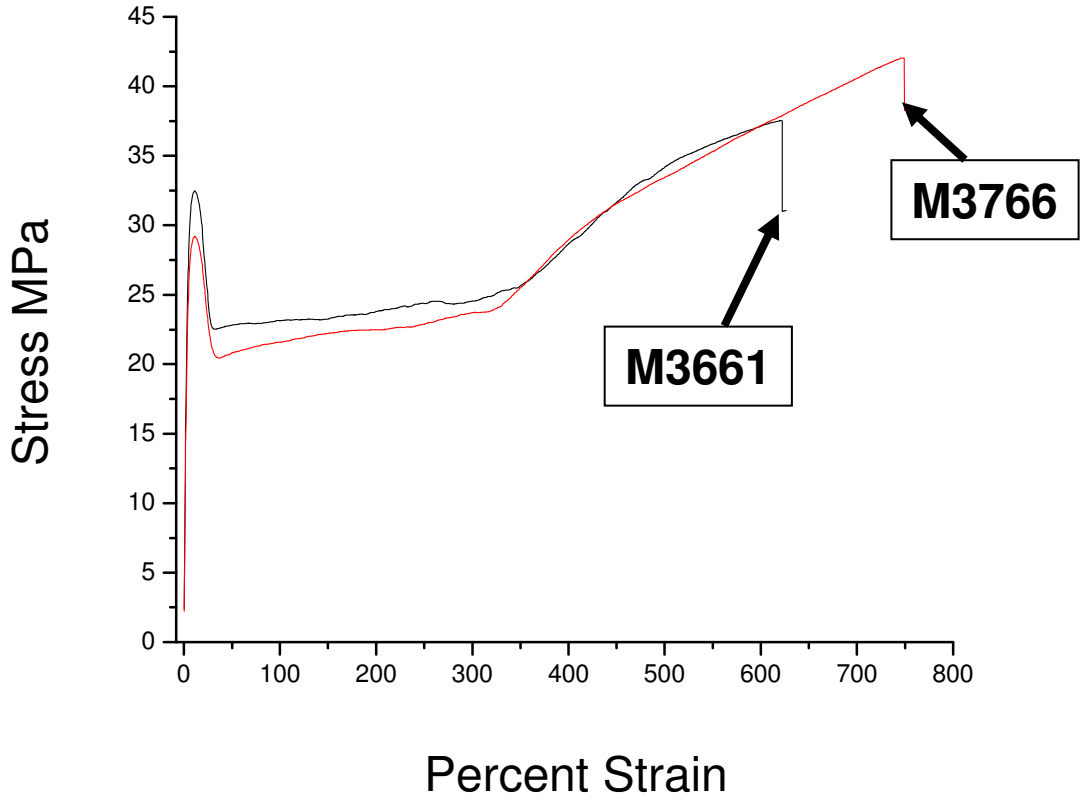
Mechanical Testing - Composites

PP 1751/M3661
20/80 S/C
Fiber Composite



Mechanical Testing - Composites

Injection Molded Polypropylenes (isotropic)



Thermal/Mechanical Analysis

Differential Scanning Calorimeter (DSC)

- *TA Instruments Q100*
- Analyzes phase transitions such as crystallization, glass transition, curing, and certain chemical reactions
- Temperature range is -90°C to 725°C
- Features - modulated DSC, autosampler, and refrigerated cooling system.

Dynamic Mechanical Analyzer (DMA)

- *TA Instruments Q800*
- Measures the viscoelastic properties of solid samples
- Measures in cantilever, 3-point bend, shear, compression, and tension modes
- Temperature range is -150°C to 600°C.

Thermogravimetric Analyzer (TGA)

- *TA Instruments High-Resolution 2950*
- Temperature range – ambient temperature up to 1000°C
- Precisely measures the weight of a sample in relation to changes in temperature
- Determines degradation temperatures, absorbed moisture content, and solvent residues

Thermogravimetric Analyzer TMA

- *TA Instruments 2940*
- Measures the deformation of a sample under an applied force
- Analyzes coefficient of thermal expansion, softening, sintering, and glass transition temp
- Temperature range is -150°C to 1000°C

Dielectric Analyzer (DEA)

- *TA Instruments 2970*
- Measures the electrical response of a material in response to oscillating voltage
- Measures ionic conductivity, characterizes phase transitions involving dipolar groups
- Monitors curing reactions
- Temperature range is -150°C to 500°C.

Instron 5500R

Compression and Tensile Testing

Load cells

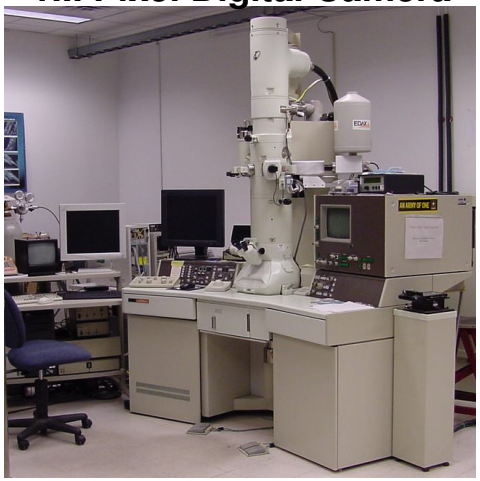
- 100N (22.5lbs)
- 1kN (225lbs)
- 10kN (2250lbs)

Assorted grips

Electron Microscopy

Scanning Electron Microscope (SEM)
Zeiss EVO60 SEM
3nm Resolution EDS Detector
Electron Beam Lithography System (50nm resolution)

Transmission Electron Microscope (TEM)
Jeol 2010 TEM
3A˚ Resolution
STEM mode
EDS detector
Gatan Image Filter (gif)
1M Pixel Digital Camera



Environmental Scanning Electron Microscope (ESEM)
Phillips XL30 ESEM
Wet, variable pressure SEM imaging
Tensile stage
EDS detector
Hi-temp heating stage

Molecular/Atomic Structure

Nuclear Magnetic Resonance Spectrometer (NMR)

Bruker Avance 400MHz

High resolution liquids
High resolution solids and semi-solids
Diffusion in solids
Variable temperature control

X-Ray Diffractometer

Bruker D8 Discover

Wide angle and small angle
Crystal analysis software

Atomic Force Microscopes

Atomic Force Microscopes

Veeco Dimension III *(originally built by Digital Instruments)*
- *General imaging in contact mode*
- *Electrochemical contact mode AFM*
- *Scanning Tunneling Microscopy (STM)*

Veeco Dimension IIIA *(originally built by Digital Instruments)*
- *General imaging in contact and non-contact (intermittent) mode*
- *Imaging in liquid*
- *Magnetic Force Microscopy*
- *Lateral (Friction) Force Microscopy*

Nanonics Imaging Ltd. MultiView 1000
- *General imaging in contact and non-contact (intermittent) mode*
- *Imaging in liquid*
- *Near-field Scanning Optical Microscopy (NSOM)*
- *Nano-Thermal Analysis*
- *Confocal Microscopy*
- *Detection of change in refractive index of materials*
- *Fluorescence Microscopy*
- *3-D Lithography*
- *Environmental Chamber with Vacuum pump and Cooling unit*

Optical Analysis

Lasers

Continuum Nd/YAG Leopard picosecond laser
50ps pulse width, 1064, 532, and 355nm wavelengths

Continuum Optical Parametric Generator (pumped by Leopard)
Tunable from UV to red

Continuum Nd:YAG/Ruby Custom Nanosecond Laser
Nd:YAG: 10 ns pulse width
1064, 532 nm output
Ruby: 30 ns pulse width
694 nm output

Coherent Innova Ar/Kr laser
Continuous wave
Tunable output from UV to red wavelengths

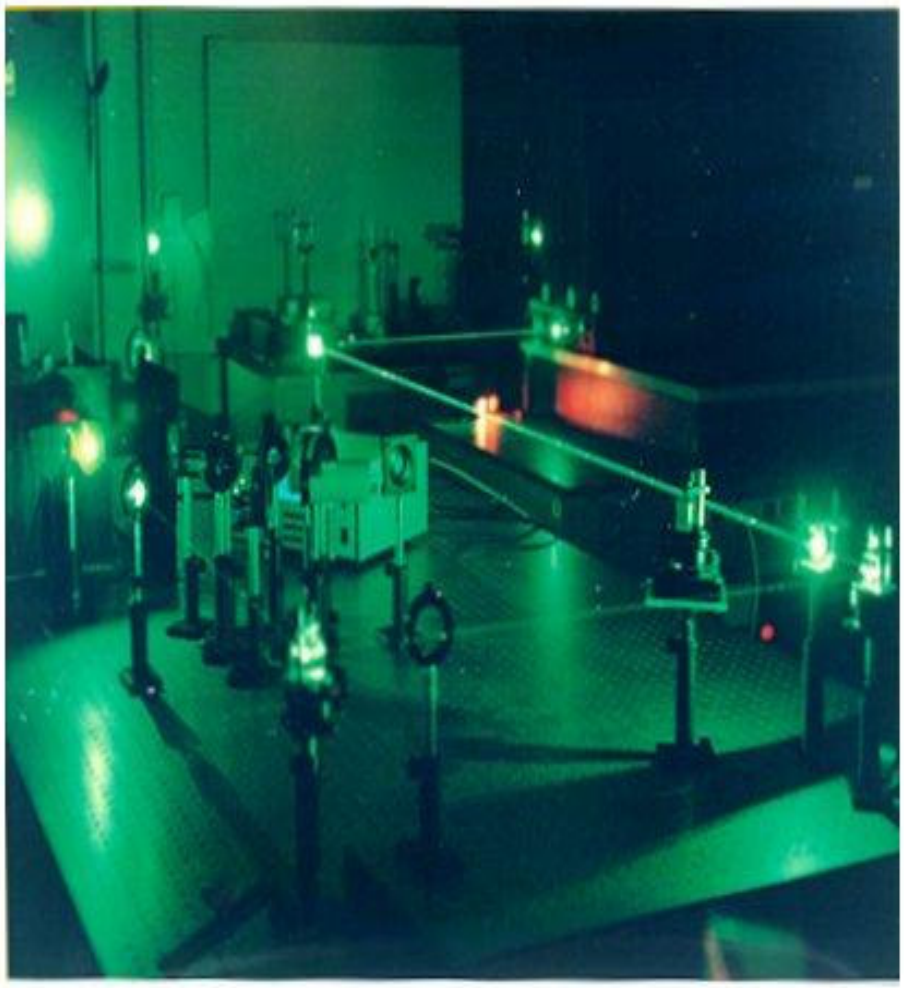
Light Age Model 101 PAL Alexandrite Laser
50 ns pulse width
Tunable output 650 nm – 750 nm
Stokes and anti-stokes raman cells

LeCroy LC574A 4 GHz Oscilloscope

Spectrophometers

Perkin Elmer Lambda 900 UV/Vis/NIR spectrophometer
UV-VIS-NIR (186nm – 3300nm)
Liquid/solid samples -
transmission absorbance and reflectance spectra
60mm and 150mm integrating spheres
Optical bench accessory for system customization

Ocean Optics UV and visible fiber optic spectrometers



High Performance Fiber COE Potential Collaborative Projects

NSRDEC is Seeking Partners for:

Novel Bi/Tri-component Fiber Development

- Optical Fibers
- Electronic Fibers
- High Strength Fibers
- Flame Retardant Fibers
- Reactive Fibers

Prototype Woven Textile Production

- Production of Small Swatches
- Performance Specification Testing

Prototype Non-woven Textile Production

- Small Sample Production
- Performance Specification Testing